AN APPLICATION OF DIRECT-SEQUENCE SPREAD-SPECTRUM ULTRASONIC TO GLOBAL INSPECTION OF BRIDGE COMPONENTS

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INTRODUCTION

Direct-Sequence Spread-Spectrum Ultrasonic Evaluation (DSSSUE) offers solutions to unsolved inspection problems. A "better mouse-trap", i.e., an improvement in technology that offers an alternative solution to problems that already have adequate solutions, generally does not make it in the market place for economic reasons. We cannot over-emphasize this aspect of the technology as there must be a clear perception of "new technology" and that the new technology is automatically economical, because it offer solutions were none existed before. DSSSUE incorporates a correlation receiver. The correlation peak to correlation noise floor effectively determines the "dynamic range" of the system and, therefore, its sensitivity. The sensitivity of DSSSUE is essentially limited by the cost of the technological implementation (memory and quantization levels) and processing time (length of correlation sequence). This results in a new technology that can be made extremely sensitive to changes in a test object, is operable over a broad range of frequencies, and is adaptable to a large number of inspection scenarios, including bridge components.

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$$R_{sr}(\tau) = h_c(t) * \{s(t-\tau)[s(t) * h_0(t)]\}$$

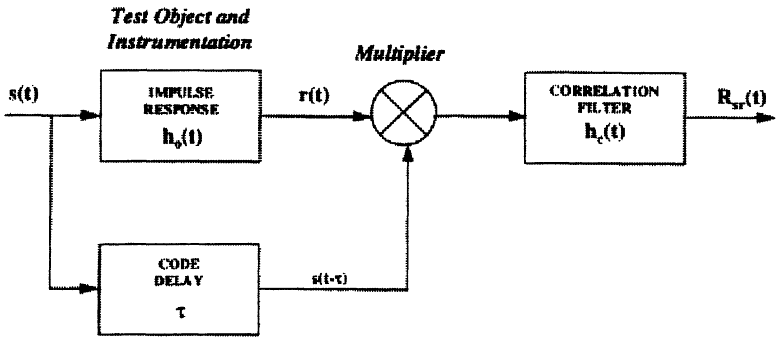


Figure 1. Signal processing model for the spread-spectrum system

BACKGROUND

In ultrasonic inspection, the DSSSUE waveform has been adapted from similar waveforms used in high-technology communication and navigation systems such as NAVSTAR Global Positioning System (GPS) and Personal Communications Network [1]. In essence, a continuously transmitted sine wave is biphase modulated with a pseudorandom sequence of pulses. The pseudorandom sequence is chosen from a class of binary sequences that have good correlation properties. When the sine wave is modulated with the sequence, its spectrum is spread out over the entire frequency spectrum of the transducer.

In Fig. 1, a correlation signature, $R_{sr}(\tau)$ for the test object is obtained by correlating a delayed replica of the transmitted signal with the received signal. By comparing the original, or reference, correlation signature with one taken at a later date or from an identical object, DSSSUE instrumentation can determine if changes have occurred.

The method is global in the sense that it floods the structure with ultrasound and, thus, no scanning is required. This is a great advantage in that the detailed scanning is difficult due to weather and hard-to-reach places. In the DSSSUE System, a continuously transmitted signal of wide band acoustic energy is used to flood the test object or structure with ultrasound. As with pulse-echo systems, this signal also propagates in the material and is scattered or reflected from the various object surfaces and from inhomogeneities (which may include flaws) within the object. However, unlike pulse-echo systems, there is no equivalent "time-of-arrival" or transit time concept inherent in the resulting correlation function.

What the DSSSUE System really does is to measure the composite characteristic of the entire acoustic system (structure and transducers) and measure the cross-correlation functions

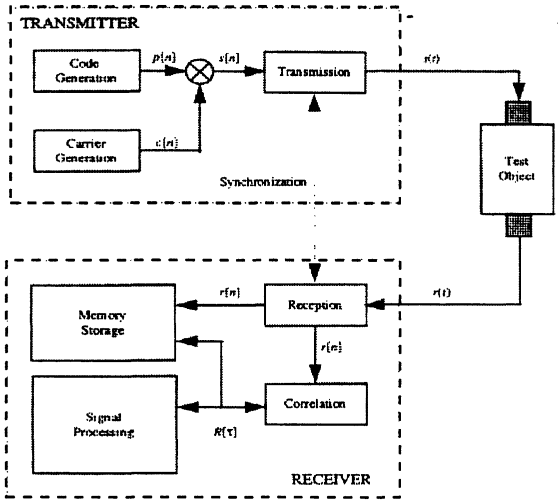


Figure 2. Block diagram of generic direct-sequence spread-spectrum instrumentation.

between the various input and output transducers of the composite system. This is the reason a transit time concept does not generally apply.

The advantage of this approach is that the cross-correlation functions represent signatures for the test object that can be used to detect changes in object characteristics, such as volume, shape, dimension, composition, density, homogeneity, and acoustic velocity. The ability to measure the changes of so many of the properties of the structure gives the DSSSUE System a significant advantage over pulse-echo ultrasonics. When a baseline cross-correlation signature is established, a condition assessment can be made by comparing the baseline signature with one taken at a later point in time. The governing equations of the technology indicate (and experimental results to date have confirmed) that there is a one-to-one correspondence between correlation signature and any type of change in the part or structure. In other words, different types of changes or identical changes in different locations show up uniquely in the correlation signature.

The two prototype instruments were built and are continually being tested and applied to new inspection problems. The first prototype, represented in Fig. 2, is mainly hardware, using analog methods for most of the signal processing. The hardware approach would be less expensive to manufacture and is likely to have faster processing times suitable for assembly line environments where piece part correlation signatures are compared to a standard reference signature. The second prototype makes use of commercial instrumentation shown in Fig. 3 and is mainly software, where all signal generation and processing is done in the computer. The software approach is the most flexible and works well in a laboratory setting since it's relatively easy to change frequencies and other parameters, optimizing the instrument to the object or structure being monitored.

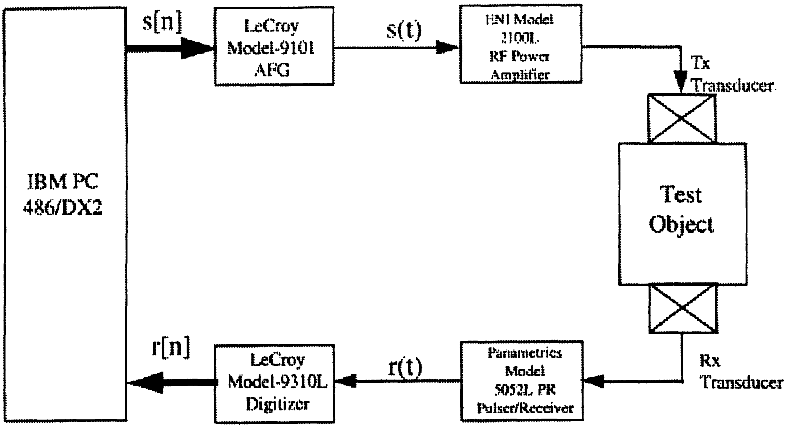


Figure 3. Block diagram of DSSSUE instrument making use of off-the-shelf instrumentation with signal generation and signal processing done in the PC.

Direct-Sequence Spread-Spectrum Ultrasonic Evaluation offers significant inspection capability in parts and structures with one or more of the following characteristics; 1) geometries preventing straight forward pulse-echo or pitch catch interpretation due to surface boundary conditions, constrained wave modes, mode conversions, 2) geometries with restricted access preventing conventional scanning, and 3) high attenuation materials. Low noise floor levels made possible by spread-spectrum allow usable signal to penetrate and flood very large structures making the method suitable for bridges.

It must be emphasized that Direct-Sequence Spread-Spectrum Ultrasonic Evaluation is very sensitive to any and all changes in a part or structure that effects the propagation and/or reflection of sound. In civil structures, for example, where acoustic propagation is effected by daily and seasonal changes in temperature and humidity and the continuous aging of concrete, an expert system would likely be employed to "filter" expected changes from those changes representing fracture, corrosion, or other forms of distress desired to be monitored.

APPLICATION TO CIVIL STRUCTURES

The DSSSUE prototype instruments were build as part of a technology transfer program at Iowa State University. During our two year project, we at CNDE began a collaboration with Keven Rens, who was a Ph.D. student initially, and several of the faculty of the Civil and Construction Engineering Department.

A joint proposal was submitted to the NFS to do a study correlating DSSSUE acoustic signatures with three types of distress in concrete in four test specimens in a controlled environment. When funded, we will study corrosion of the concrete, corrosion of the steel rebar and disbond between the concrete and rebar.

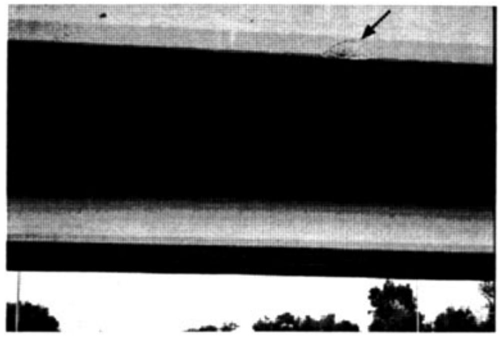
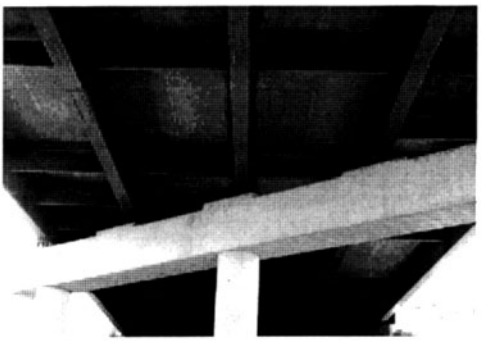


Figure 4a. - Concrete bridge, Ames, Iowa. Figure 4b. Concrete bridge, damage detail.



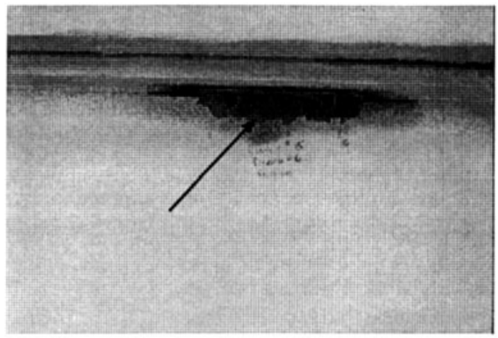
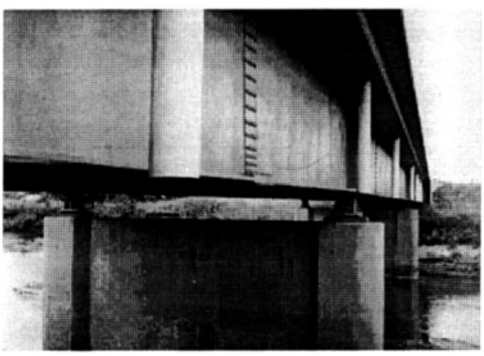


Figure 5a. Steel structure bridge, Ames, Iowa. Figure 5b. Steel structure bridge, detail.



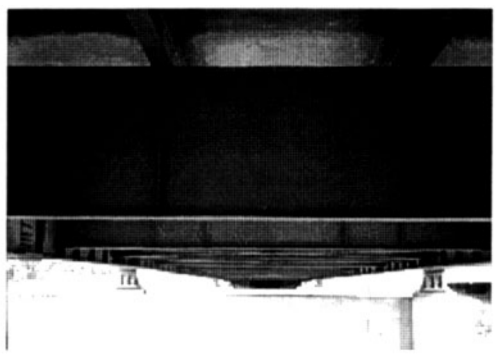


Figure 6a. Fatigue critical bridge, I-35 (Iowa). Figure 6b. Detail of roadbed support structure.

Bruce Brekke, of the Iowa DOT, conducted a tour of three different types of bridges in the Ames area which are suitable candidates for inspection with DSSSUE. The first bridge shown in Fig. 4a is a pre-stressed re-enforced concrete bridge part of US 30. The damage shown in Fig. 4b was caused by illegal height load impacting the concrete I-beam. The second bridge, Fig. 5a, is a steel multiple-I-beam support bridge also part of US 30. A several inch long fatigue crack is detailed in Fig. 5b. The third bridge, the southbound lanes of I-35 a few miles south of Ames, shown in Figs 6a and 6b. is a "fatigue critical bridge". If either of the two main roadbed support structure I-beams cracks, the bridge collapses.

Several preliminary steps are being pursued in preparation for the DSSSUE monitoring of these bridge structures. The Iowa DOT has provided drawing of the three bridges from which CAD models are being generated. The CAD models provide the "front end" to an ultrasonic modeling module being developed under other programs at the Center of Nondestructive Evaluation. The ultrasonic modeling will give an indication of the insonification patterns as a function of transducer placement, thus predicting how well the sound field will cover areas of high stress.

Working with the Civil and Construction Engineering Department and their Structures Lab at Iowa State University, we are monitoring, with DSSSUE, a section of a highway bridge as it is being loaded to the point of failure. Fig. 7 shows the 30 foot section of Aluminum girder and roadbed being prepared for loading.

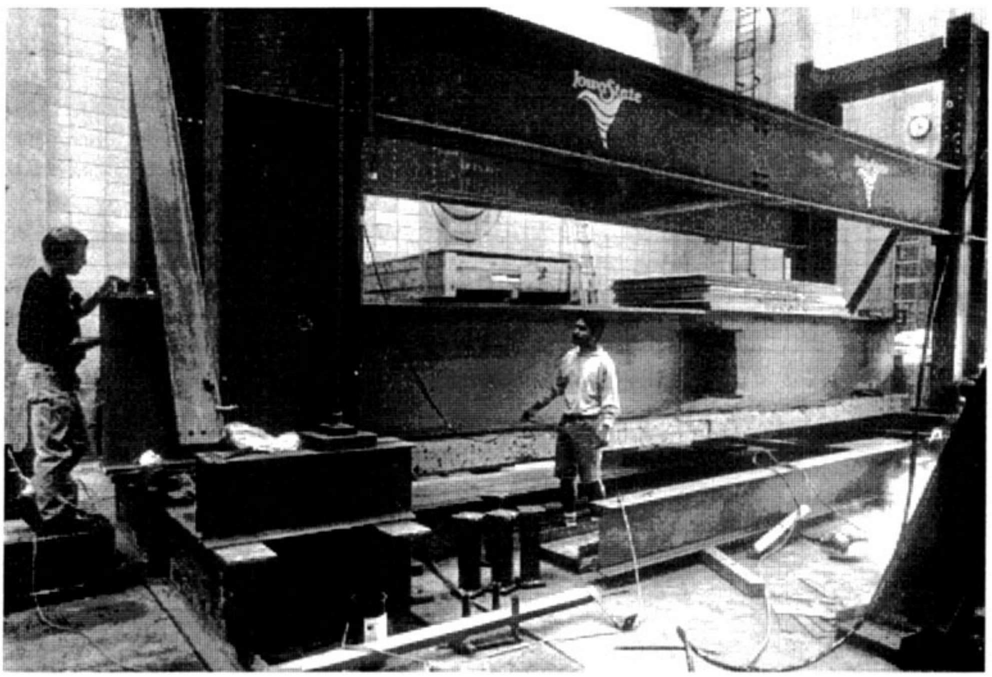


Figure 7. Preparation of highway bridge section, Structures Lab at Iowa State University

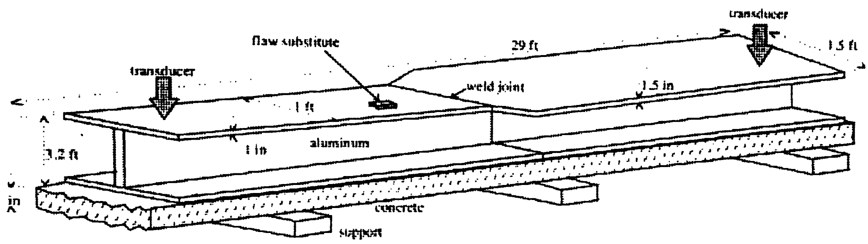


Figure 8. Schematic drawing and table of the bridge section and test cases.

Table 2. Bridge girder experiment conditions.

datum	setup	contact area
Baseline	Aluminum Bridge girder (no flaw)	-----
Flaw-1	One block laying flat on the girder	12.5 sq in
Flaw-2	One block standing on its longer side	1.25 sq in
Flaw-3	Both blocks standing on their longer sides	2.5 sq in
Flaw-4	Both block laying flat on the girder	25 sq in

Tests were carried out in the Structures Lab on the aluminum I-beam bridge girder of the form shown in Fig. 8 to determine sensitivity to change. In order to simulate the change in the test object, two identical blocks of steel 5"x2.5"x0.5" were used to acoustically simulate small fracture flaws. These blocks were placed in different orientations at a fixed location on the I-beam with contact areas shown in Table 2 (Fig. 8). Correlation difference energy (CDE) was computed for the five cases. The histogram distribution of the CDE is plotted in Fig. 9. The position of each flaw CDE in the histogram is consistent with the size of the simulated flaw. Moreover, it was found that transducer placement was not critical and similar results were obtained for different transducer positions.

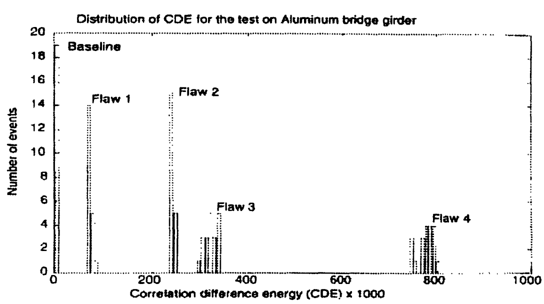


Figure 9. Distribution of the correlation difference energy - Aluminum bridge girder

Early this fall, we begin monitoring a new section of Iowa Highway 3 in Franklin County, Iowa. Very shortly after the new pavement is poured, we will implant six stainless steel disks which will serve as registration points and transducer interfaces to the concrete roadbed. Three disks spaced ten feet apart will provide three interface points on one slab of concrete. Three more disks will be implanted on a slab on the opposite side of the highway. We expect to make periodic inspections, remounting the transducers for each subsequent inspection. We expect to have to sort out competing features in the correlation signatures corresponding to concrete aging, temperature, stress, wear, geometric deformation due to ground shifting and so on.

CONCLUSIONS

Direct-Sequence Spread-Spectrum Ultrasonic Evaluation prototypic instruments have demonstrated the ability to detect and differentiate the location and orientation of very small "defects" representing sulfite stringer inclusions in small steel assembly line parts [2,3], by comparing correlation signatures of the defective part with that of a known good reference part. The technology has also been effective in detecting small changes, representative of small fatigue cracks in a large section of bridge structure made up of I-beams embedded in concrete. Permanently mounted transducers can eliminate variations due to couplant changes. A smooth surface is not needed as is the case for scanning. The sensor part of the instrument can be weatherproofed and should require little maintenance. The method readily adapts itself to the use of telemetry methods for remote collection and continuous monitoring of the bridge.

ACKNOWLEDGMENT

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